APPLICATION

FOR

UNITED STATES LETTERS PATENT

TITLE: WAVELENGTH MONITOR

APPLICANT: MINORU MAEDA

Declaration and Power of Attorney for Patent Application
特許出願宣言書及び委任状

Japanese Language Declaration
日本語宣言書

下記の氏名の発明者として、私は下記の通り宣言します。

As a below named inventor, I hereby declare that:

私の住所、郵送先、国籍は下記の私の氏名の後に記載された通りです。

My residence, post office address and citizenship are as stated next to my name.

下記の名称の発明に関して請求範囲に記載され、特許出願している発明内容について、私が最初かつ唯一の発明者（下記の氏名が一つの場合）もしくは最初かつ共同発明者であると（下記の氏名が複数の場合）信じています。

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

WAVELENGTH MONITOR

上記発明の明細書（下記の欄で×印がついていない場合は、本状に添付）は、

the specification of which is attached hereto unless the following box is checked:

☐ ___年___月___日に提出され、米国出願番号または特許協力条約国際出願番号を_____とし、（該当する場合）___年___月___日に訂正されました。

☐ was filed on _____
as United States Application Number or PCT International Application Number
_____ and was amended on
_____ (if applicable)

私は、特許請求範囲を含む上記補正による補正後の明細書を検討し、内容を理解していることをここに表明します。

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendement referred to above.

私は、連邦規則法典第37編第1条56項に規定されるとおり、特許性の有無について重要な情報を開示する義務があることを認めます。

I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56.

Declaration and Power of Attorney for Patent Application
特許出願宣言書及び委任状

私は、米国法典第35編119条 (a) - (d) 項又は365
条(b) 項に基づき下記の、米国以外の国の少なくとも一カ
国を指定している同編365条 (a) 項に基づく特許協力条
約国際出願、又は外国での特許出願もしくは発明者証の出
願についての外国優先権をここに主張するとともに、優先
権を主張している、本出願の前に出願された特許または発
明者証の外国出願または特許協力条約国際出願を以下に、
枠内をマークすることで、示しています。

I hereby claim foreign priority under Title 35, United
States Code, Section 119 (a)-(d) or 365(b) of any foreign
application(s) for patent or inventor's certificate, or 365(a)
of any PCT International application which designated at
least one country other than the United States, listed
below and have also identified below, by checking the box,
any foreign application for patent or inventor's certificate,
or PCT International application having a filing date before
that of the application on which priority is claimed.

Prior foreign Application(s)
外国での先行出願

			Priority not claimed 優先権主張なし
P. 2001-008589	Japan	17/January/2001	☐
(Number) (番号)	(Country) (国名)	(Day/Month/Year Filed) (出願年月日)	
			☐
(Number) (番号)	(Country) (国名)	(Day/Month/Year Filed) (出願年月日)	

私は、第35編米国法典119条 (e) 項に基づいて下記
の米国特許予備出願の権利をここに主張いたします。

I hereby claim the benefits under Title 35, United States
Code, Section 119(e) of any United States provisional
application(s) listed below.

(Application No.) (出願番号)	(Filing Date) (出願日)	(Application No.) (出願番号)	(Filing Date) (出願日)

私は、下記の米国法典第35編120条に基づいて下記
の米国特許出願の権利、又は米国を指定している特許協力
条約国際出願365条 (c) に基づく権利をここに主張しま
す。また、本出願の各請求範囲の内容が米国法典第35編
112条第1項で規定された態様で先行する米国特許出願
または特許協力条約国際出願に開示されていない限り、連
邦規則法典第37編1条36項で定義されたその先行米国
出願番号提出日以降で国内または特許協力条約国際提出日ま
での期間中に入手し得た、特許性に関する重要な情報につ
いて開示義務があることを認識しています。

I hereby claim the benefit under Title 35, United States
Code, Section 120 of any United States application(s), or
365(c) of any PCT International application designating
the United States, listed below and, isofar as the subject
matter of each of the claims of this application is not
disclosed in the prior United States or PCT International
application in the manner provided by the first
paragraph of Title 35, United States Code Section 112, I
acknowledge the duty to disclose information which is
material to patentability as defined in Title 37, Code of
Federal Regulations, Section 1.56 which became available
between the filing date of the prior application and the
national or PCT International filing date of application.

(Application No.) (出願番号)	(Filing Date) (出願日)	(Status: Patented, Pending, Abandoned) 〈現況：特許許可済、係属中、放棄済〉
(Application No.) (出願番号)	(Filing Date) (出願日)	(Status: Patented, Pending, Abandoned) 〈現況：特許許可済、係属中、放棄済〉

私は、私自身の知識に基づいて本宣言書中で私が行なう
表明が真実であり、かつ私の入手した情報と私の信じると
ころに基づく表明が全て真実であると信じていること、さ
らに故意になされた虚偽の表明及びそれと同等の行為は米
国法典第18編第1001条に基づき、罰金または拘禁、
もしくはその両方により処罰されること、そしてそのよう
な故意による虚偽の表明を行なえば、出願した、又は既に
許可された特許の有効性が失われることを認識し、よって
ここに上記のごとく宣誓を致します。

I hereby declare that all statements made herein of my
own knowledge are true and that all statements made on
information and belief are believed to be true; and further
that these statements were made with the knowledge that
willful false statements and the like so made are
punishable by fine or imprisonment, or both, under Section
1001 of Title 18 of the United States Code and that such
willful false statements may jeopardize the validity of the
application or any patent issued thereon.

FISH & RICHARDSON P.C.
Page 2 of 3

Declaration and Power of Attorney for Patent Application
特許出願宣言書及び委任状

委任条：私は下記の発明者として、本出願に関する一切の
手続きを米特許商標局に対して送行する代理人として、
下記の者を指名いたします。（代理人の氏名及び登録番号
を明記のこと）

POWER OF ATTORNEY: as named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith *(list name and registration number)*

John B. Pegram, Reg. 25,198	Frederick M. Rabin, No. 24,488	William J. Hone, Reg. 26,739
Gary A. Walpert, Reg. 26,098	Richard P. Ferrara, Reg. 30,362	Samuel Borodach, Reg. 38,388
Stephan J. Filipek, Reg. 33,384	Andrew N. Parfomak, Reg. 32,431	

書類送付先：   Send correspondence to:

The person indicated in the cover letter accompanying the application or to: FISH & RICHARDSON P.C., Suite 2800, 45 Rockefeller Plaza, New York, NY 10111.

直接電話連絡先： (名前及び電話番号)   Direct Telephone Calls to: *(name and telephone number)*

The person indicated in the cover letter accompanying the application or to 212-765-5070, referencing the Attorney's Docket No. or application Serial No.

唯一または第一発明者			Full name of sole first inventor Minoru MAEDA	
発明者の署名	日付		Inventor's signature *Minoru Maeda*	Date January 16, 2002
住所			Residence Tokyo, Japan	
国籍			Citizenship Japan	
郵送先			Post Office Address c/o Ando Electric Co., Ltd., 29-3, Kamata 5-chome, Ota-ku, Tokyo, Japan	
第二共同発明者			Full name of second joint inventor, if any	
第二共同発明者	日付		Second inventor's signature	Date
住所			Residence	
国籍			Citizenship	
郵送先			Post Office Address	

(第三以降の共同発明者についても同様に記載し、署名を
すること・

(Supply similar information and signature for third and subsequent joint inventors.)

FISH & RICHARDSON P.C.
Page 3 of 3

WAVELENGTH MONITOR

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to wavelength
monitors, which are typically used in the field of
optical measurement technology to measure the wavelengths
of light sources oscillating in a single mode.

2. Description of the Related Art

Light sources for single-mode oscillating DFB-LD
(distributed feedback laser diode) and DBR-LD
(distributed Bragg reflector laser diode) have a problem
of experiencing drifts as they are used for a prolonged
period of time, so in a DWDM (dense wavelength division
multiplexing) system, the wavelengths of such light
sources must be controlled by measuring them at
appropriate times.

Wavelength tunable light sources of an external
resonator type using a diffraction grating are
extensively used to measure the wavelength
characteristics of optical components. While they are
capable of setting a desired value of wavelength over a
broad range (≥ 100 nm), this type of light sources are
sensitive to external effects and temperature changes in
particular affect the wavelength stability. In addition,

as the DWDM system becomes adaptive to higher degrees of multiplexing, it is required to increase the probability that the light source has stable wavelengths.

Among the conventional devices for measuring the wavelengths of light sources, the most commonly used are spectroscopes such as an optical spectrum analyzer that rotate a diffraction grating by a moving mechanism.

However, the moving mechanism in such spectroscopes makes them bulky and poses other problems such as limited long-term reliability. To deal with these difficulties, various types of wavelength monitor have been developed that measure the wavelengths of light sources at appropriate times with a
compact design having no moving mechanism.

Among these wavelength monitors, one called a wavelength locker is used to control the wavelength of a DFB-LD light source with a structure that uses optical components such as interference film based filters and diffraction gratings.

The wavelength monitor called a wavelength locker can only be operated over a narrow wavelength range but using no mechanical moving parts, it has high reliability, can be reduced in size, requires no large-scale processing with software and, hence, is suited to the purpose of controlling the wavelengths of light

sources such as one for DBF-LD that seldom vary in wavelength. There is, however, a problem in that the operating wavelength is limited by the wavelength characteristics of the components used such as filters.

A conventional wavelength monitor that is free from this problem may be a "wavelength change measuring apparatus" disclosed in JP 11-034697 A. A block diagram for the configuration of this apparatus is shown in Fig. 6 as a reference for the following description of the apparatus.

As shown in Fig. 6, the "wavelength change measuring apparatus" under consideration is basically composed of an input fiber 201, a collimating lens 202, a beam splitter 203 as a first splitting means, a first reflector 204, a second reflector 205 with a step of $d = \lambda_0/8$, a reflecting prism 206 as a second splitting means, a first photo-detector 207, a second photo-detector 208, and a signal processing circuit 209 for processing signals from the two photo-detectors.

Measuring light emerging from the input fiber 201 is collimated and launched into the beam splitter 203 as the first splitting means provided on the axis of the emerging light, whereby it is split into two beams, one directed toward the first reflector 204 and the other toward the second reflector 205. The first reflector 204

and the second reflector 205 are provided normal to the optical paths of the split beams of collimated light emerging from the beam splitter 203 and their optical axes are adjusted such that each of the split beams of collimated light will be reflected back to the beam splitter 203 by travelling through the same optical path.

The second reflector 205 is a plane reflector having a step of $d = \lambda_0/8$, so when a light beam is reflected by the second reflector 205 and travels through the return path, one half of the beam plane generates a difference of $\lambda_0/4$ in pathlength (λ_0 is the center wavelength in the measurable wavelength range and may take the value of 1550 nm).

The two beams of collimated light that have been reflected by the first reflector 204 and the second reflector 205 make a second entry into the beam splitter 203, where they are recombined before entering the reflecting prism 206 as the second splitting means.

The reflecting prism 206 is provided such that the axial plane where the pathlength difference of $\lambda_0/4$ has been generated coincides with the edge tip surface of the reflecting prism 206; the recombined parallel light incident on the reflecting prism 206 is split into two beams by its edge tip surface and the split beams are launched into the first photo-detector 207 and the second

- 4 -

photo-detector 208 which are provided on their optical axes. The light beams entering the two photo-detectors are output to the signal processing circuit 209 as currents that depend on their optical intensity. The signal processing circuit 209 compares the light intensities from the two photo-detectors and perform necessary arithmetic operations to output wavelength data.

The changes in light intensity vs. wavelength that are obtained with the ordinary Michelson interferometer are expressed by the following eq. 1. A normalized Gaussian distribution in a light beam plane gives a uniform light intensity, which varies uniformly with changing wavelength.

$$I = [1 + \cos[4\pi{*}\Delta L/\lambda]]/2 \qquad\qquad (1)$$

In eq. 1, I signifies the normalized light intensity received by a photo-detector; λ is the wavelength of the light input from the light source; ΔL is the pathlength difference in the Michelson interferometer.

In the design described above, a plane reflector having a step of $d = \lambda_0/8$ is used as the second reflector 205, so when a light beam is reflected by the second reflector 205 and travels through the return path, one

- 5 -

half of the beam plane generates a pathlength difference of $\lambda_0/4$, thereby producing periodic interference light intensity signals with a phase difference of $\pi/2$.

Using the interference light intensity signals with a phase difference of $\pi/2$, one can determine the amounts and directions of changes in the wavelength of a light source.

However, the above-described conventional wavelength monitor, or the "wavelength change measuring apparatus" disclosed in JP 11-034697 A, does not satisfy the low-cost requirement since a step mirror, or a mirror specially designed to have a step of $d = \lambda_0/8$, must be used.

As a further problem, diffraction occurs at the boundary between the step and the non-step area of the step mirror, producing distorted interference light signals.

SUMMARY OF THE INVENTION

The present invention has been accomplished to solve the aforementioned problems of the conventional and its principal object is to provide a low-cost wavelength monitor for measuring the wavelength of a single mode oscillating light source with such a design that a phase difference of $\pi/2$ is generated in two interference light

intensity signals without using any specially designed
optical components and that the phase difference can be
adjusted after fixing the individual optical components.

According to the present invention, there is
provided a wavelength monitor comprising:

a Michelson interferometer optical system
comprising:

an optical element for collimating an incident
light beam from a light input section to generate a
collimated light beam;

a first beam splitter for splitting the
collimated light beam from the optical element into
two split beams;

a first reflector and a second reflector each
for reflecting the respective split beams from the
first beam splitter; and

an interference pattern generating means for
inclining the wavefront of the reflected beam from
the one of the first reflector and the second
reflector, thereby to generate an interference light
beam having an interference pattern in the light
intensity distribution in an plane of the
interference light beam;

a second beam splitter for splitting the

interference light beam received from the first beam

splitter in a different direction from the incident

direction of the interference light beam;

a first photo-detector and a second photo-detector

for receiving the respective beams of the interference

light split by the second beam splitter;

a first slit provided in front of the first photo-

detector;

a second slit provided in front of the second photo-

detector; and

a signal processor for counting intensity changes of

the light beams from the first photo-detector and the

second photo-detector.

According to the present invention, there is

provided a wavelength monitor comprising:

a Mach-Zehnder interferometer optical system

comprising:

an optical element for collimating an incident

light beam from a light input section to generate a

collimated light beam;

a first beam splitter for splitting the

collimated light beam from the optical element into

two split beams;

a first reflector and a second reflector for
reflecting the respective split beams from the first
beam splitter;

a second beam splitter for recombining the
reflected light beams from the first reflector and
the second reflector; and

an interference pattern generating means for
inclining the wavefront of the reflected beam from
the one of the first reflector and the second
reflector, thereby to generate an interference light
beam having an interference pattern in the light
intensity distribution in an plane of the
interference light beam;

a third beam splitter for splitting the interference
light beam received from the second beam splitter;

a first photo-detector and a second photo-detector
for receiving the respective interference light beams
split by the third beam splitter;

a first slit provided in front of the first photo-
detector;

a second slit provided in front of the second photo-
detector; and

a signal processor for counting intensity changes of the light beams from the first photo-detector and the second photo-detector.

According to the present invention, there is provided a wavelength monitor comprising:

a Mach-Zehnder interferometer optical system comprising:

an optical element for collimating an incident light beam from a light input section to generate a collimated light beam;

a first beam splitter for splitting the collimated light beam from the optical element into two split beams;

a first reflector and a second reflector for reflecting the respective split beams from the first beam splitter;

a second beam splitter for recombining the reflected light beams from the first reflector and the second reflector; and

an interference pattern generating means for inclining the wavefront of the reflected beam from the one of the first reflector and the second reflector, thereby to generate an interference light beam having an interference pattern in the light

intensity distribution in an plane of the

interference light beam;

a first photo-detector for receiving the

interference light beam transmitted from the second beam

splitter in one of two directions;

a second photo-detector for receiving the

interference light beam transmitted from the second beam

splitter in the other direction thereof;

a first slit provided in front of the first photo-

detector;

a second slit provided in front of the second photo-

detector; and

a signal processor for counting intensity changes of

the light beams from the first photo-detector and the

second photo-detector.

According to the present invention, there is

provided a wavelength monitor comprising:

a Mach-Zehnder interferometer optical system

comprising:

an optical element for collimating an incident

light beam from a light input section to generate an

collimated light beam;

a first beam splitter for splitting the
collimated light from the optical element into two
beams;

a first reflector for reflecting one of the two
beams split by the first beam splitter;

a second reflector for reflecting the light beam
reflected by the first reflector;

a second beam splitter for recombining the other
of the two beams split by the first beam splitter
with the light beam reflected by the second
reflector; and

an interference pattern generating means for
inclining the wavefront of the reflected beam from
the one of the first reflector and the second
reflector, thereby to generate an interference light
beam having an interference pattern in the light
intensity distribution in an plane of the
interference light beam;

a third beam splitter for splitting the interference
light beam received from the second beam splitter;

a first photo-detector and a second photo-detector
for receiving the respective beams of the interference
light split by the third beam splitter;

- 12 -

a first slit provided in front of the first photo-detector;

a second slit provided in front of the second photo-detector; and

a signal processor for counting intensity changes of the light beams from the first photo-detector and the second photo-detector.

According to the present invention, there is provided a wavelength monitor comprising:

a Mach-Zehnder interferometer optical system comprising:

an optical element for collimating an incident light beam from a light input section to generate a collimated light beam;

a first beam splitter for splitting the collimated light beam from the optical element into two beams;

a first reflector for reflecting one of the two beams split by the first beam splitter;

a second reflector for reflecting the light beam reflected by the first reflector;

a second beam splitter for recombining the other of the two beams split by the first beam splitter

with the light beam reflected by the second
reflector; and

an interference pattern generating means for
inclining the wavefront of the reflected beam from
the one of the first reflector and the second
reflector, thereby to generate an interference light
beam having an interference pattern in the light
intensity distribution in an plane of the
interference light beam;

a first photo-detector for receiving the
interference light beam transmitted from the second beam
splitter in one of two directions;

a second photo-detector for receiving the
interference light beam transmitted from the second beam
splitter in the other direction thereof;

a first slit provided in front of the first photo-
detector;

a second slit provided in front of the second photo-
detector; and

a signal processor for counting intensity changes of
the light beams from the first photo-detector and the
second photo-detector.

According to the wavelength monitors of the
invention, interference light intensity signals having a

phase difference are produced by the means of generating an interference pattern in an interference light beam plane, so the specially designed reflector (step mirror) which has been used in the conventional wavelength monitors is no longer necessary, making it possible to realize cost reduction by parts standardization.

In addition, slits narrower than the spacing between interference fringes are positioned in front of the photo-detectors for light reception and this provides interference light intensity characteristics having almost ideal changes in light intensity.

In the wavelength monitors, the reflected light from neither of the two reflectors returns to the input section, thereby insulating it from any adverse effects.

The wavelength monitors have no need to use a third beam splitter and, hence, can be constructed at lower cost in smaller size.

If desired, said interference pattern generating means may be realized by inclining said first reflector and/or said second reflector. Alternatively, said interference pattern generating means may be realized by inserting a wedge substrate into one of the two optical paths in said optical system. Still alternatively, said interference pattern generating means may be realized by

inclining said first beam splitter and/or said second beam splitter.

These designs permit adjusting the amount of inclination of the wavefronts of the two beams of reflected light that are to interfere with each other, so the wavelength band over which the wavelength monitor can operate can be set in a desired way.

In another preferred embodiment, said first slit and/or said second slit may be variable in slit width. Alternatively, said first slit and/or said second slit may be variable in slit position. Still alternatively, light reception may be effected by said first photo-detector and/or said second photo-detector which have a detecting area diameter smaller than the diameter of interference beams and said first photo-detector and/or said second photo-detector is variable in position.

By adjusting the slit position, some latitude is provided in the control of light intensity. In addition, after fixing the individual components of the wavelength monitor, the width and position of the slit provided in front of each photo-detector are adjusted to produce interference electro-optic signals having an ideal phase difference.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a diagram showing the configuration of a wavelength monitor according to the first embodiment of the invention.

Fig. 2 is a diagram showing the configuration of a wavelength monitor according to the second embodiment of the invention.

Fig. 3 is a diagram showing the configuration of a wavelength monitor according to the third embodiment of the invention.

Fig. 4 is a diagram showing the configuration of a wavelength monitor according to the fourth embodiment of the invention.

Fig. 5 is a diagram showing the configuration of a wavelength monitor according to the fifth embodiment of the invention.

Fig. 6 is a diagram showing the configuration of a conventional wavelength monitor using a Michelson interferometer with a step mirror.

DETAIELD DESCRIPTION OF THE PRESENT INVENTION

Wavelength monitors according to the first to fifth embodiments of the invention are described with reference to Figs. 1 - 5.

First embodiment

Fig. 1 is a diagram showing configuration of a wavelength monitor 10 according to the first embodiment of the invention.

As Fig. 1 shows, the wavelength monitor 10 has a Michelson interferometer optical system 11 comprising a collimating lens (optical element) 102 for collimating the incident light from an input fiber (light input section) 101, a first beam splitter 103 for splitting the incident collimated light from the optical element 102 into two beams, and a first reflector 104 and a second reflector 105 for reflecting the respective split beams of collimated light from the first beam splitter 103.

The optical system 11 has an interference pattern generating means 12 which inclines the wavefronts of the reflected beams from the first reflector 104 and the second reflector 105 after they are recombined at the first beam splitter 103, thereby generating an interference pattern in the light intensity distribution in an interference light beam plane, and this interference pattern generating means 12 is realized by inclining the first reflector 104 and/or the second reflector 105.

The optical system 11 further includes a second beam splitter 106, a first slit 107 and a second slit 108, as

well as a first photo-detector 109 and a second photo-detector 110 that are securely provided on an optical base platform (not shown); another component of the optical system 11 is a signal processing circuit (signal processing means) 111 for processing the signals from the first photo-detector 109 and the second photo-detector 110.

Next, we describe the capabilities and operations of the first embodiment on the following pages.

The input fiber 101 guides the light from a light source (not shown) and emits it from the end face. The lens 102 is provided on the optical axis of the light emerging from the input fiber 101 and collimates the light emerging from the end face of the fiber.

The emerging collimated light from the lens 102 is launched into the first beam splitter 103 provided on its optical axis. The first beam splitter 103 splits the incident light into two beams, one being directed to the first reflector 104 and the other directed to the second reflector 105.

The first reflector 104 is provided on the optical path of one of the two beams of collimated light from the first beam splitter 103 and reflects the incident beam of collimated light such that it makes a second entry into the first beam splitter 103.

The second reflector 105 is provided on the optical path of the other of the two beams of collimated light from the first beam splitter 103 and reflects the incident beam of collimated light such that it makes a second entry into the first beam splitter 103.

The two beams of collimated light reflected by the first reflector 104 and the second reflector 105 to make a second entry into the first beam splitter 103 are recombined and emerge from said first beam splitter 103 it at two end faces, one facing the input fiber 101 and the other being different from the first end face. The intensity of the light emerging from the first end face and that of the light emerging from the second end face have inverting characteristics.

The reflected beam from the first reflector 104 and the reflected beam from the second reflector 105 that are to be recombined at the first beam splitter 103 have their optical axes adjusted to incline slightly.

Adjacent the second end face of the first beam splitter 103 which is different from the first one which faces the input fiber 101, there is provided the second beam splitter 106 on the optical axis of the emerging light. The second beam splitter 106 splits the incident interference light into two beams, one being directed to

- 20 -

the first photo-detector 109 and the other directed to the second photo-detector 110.

One of the two split beams of interference light emerging from the second beam splitter 106 is launched into the first photo-detector 109 after passing through the first slit 107 provided on its optical axis. Similarly, the other of the two split beams of interference light is launched into the second photo-detector 110 after passing through the second slit 108 provided on its optical axis.

In the system shown in Fig. 1, the collimated light is directly launched into the photo-detectors but it will be apparent to the skilled artisan that the collimated light may first be condensed with another lens (not shown) before it is received by the photo-detectors.

The first photo-detector 109 and the second photo-detector 110 may each be composed of a photodiode and after converting light to electrical signals, they output currents in accordance with the intensity of the received light.

In the signal processing circuit 111, the electrical signals proportional to the intensities of light from the first photo-detector 109 and the second photo-detector 110 are compared and subjected to necessary arithmetic

- 21 -

operations so that the wavelength of the incident light is determined and wavelength data is output.

The system is so designed that the reflected beam from the first reflector 104 and the reflected beam from the second reflector 105 that are to be recombined at the first beam splitter 103 have their optical axes adjusted to incline (to realize the interference pattern generating means 12). As a result, the wavefronts of the two beams of reflected parallel light are inclined and the intensity of light in the interference light beam plane does not have the uniformity expressed by eq. 1; instead, linear interference fringes are generated.

If all beams of interference light having narrow interference fringes are received by the photo-detectors, a wavelength change will not cause the desired change in light intensity that is expressed by eq. 1.

In addition, the interference fringes under observation appear to make a parallel shift in response to the wavelength change.

What is more, if the inclination of the wavefronts of the two beams of reflected parallel light is increased, the spacing between interference fringes decreases; if the inclination is reduced, the spacing between interference fringes increases. If the inclination of the wavefronts eventually becomes zero

- 22 -

(the two beams are parallel), a uniform light intensity
is obtained.

However, even if interference fringes are generated
in the interference light beam plane, light intensity
characteristics having almost the same changes in light
intensity as are expressed by eq. 1 can be obtained if a
slit narrower than the spacing between interference
fringes is provided in front of each photo-detector for
light reception. In addition, by adjusting the position
of the slit provided in front of each photo-detector,
some latitude is provided in the control of light
intensity.

To this end, the positions of the first slit 107 and
the second slit 108 provided in front of the first photo-
detector 109 and the second photo-detector 110,
respectively, are adjusted, thereby making it possible to
adjust the phase difference between the interference
light intensity signals being output from the two photo-
detectors.

According to the first embodiment of the invention,
the widths and positions of the slits provided in front
of the first photo-detector 109 and the second photo-
detector 110 are adjusted and this has the advantage that
the phase difference in the light intensity signals from
the two photo-detectors as determined by fixing the

individual optical elements can be controlled to produce interference light intensity signals having an ideal phase difference.

In addition, the expensive, specially designed step mirror which has been used in the conventional wavelength monitors is no longer necessary, contributing to cost reduction. The diffraction occurring at the boundary between the step and the non-step area of the step mirror is structurally absent from the design of the embodiment under consideration and there is no such problem as the occurrence of distorted interference optical signals.

Second embodiment

Fig. 2 is a diagram showing the configuration of a wavelength monitor 20 according to the second embodiment of the invention. In Fig. 2, the components which are the same as those shown in Fig. 1 are identified by the same numerals.

As Fig. 2 shows, the wavelength monitor 20 of the second embodiment has a Mach-Zehnder interferometer optical system 21 comprising a collimating lens (optical element) 102 for collimating the incident light from an input fiber (light input section) 101, a first beam splitter 103 for splitting the incident collimated light from the optical element 102 into two beams, a first

reflector 104 and a second reflector 105 for reflecting the respective split beams of collimated light from the first beam splitter 103, and a second beam splitter 106 for recombining the reflected beams of light.

The optical system 21 has an interference pattern generating means 22 which inclines the wavefronts of the reflected beams from the first reflector 104 and the second reflector 105 after they are recombined at the second beam splitter 106, thereby generating an interference pattern in the light intensity distribution in an interference light beam plane, and this interference pattern generating means 22 is realized either by inclining the first reflector 104 and/or the second reflector 105 or by inclining the first beam splitter 103 and/or the second beam splitter 106.

The optical system 21 further includes a third beam splitter 112, a first slit 107 and a second slit 108, as well as a first photo-detector 109 and a second photo-detector 110 that are securely provided on an optical base platform (not shown); another component of the optical system 21 is a signal processing circuit (signal processing means) 111 for processing the signals from the first photo-detector 109 and the second photo-detector 110.

Next, we describe the capabilities and operations of
the second embodiment on the following pages.

The first reflector 104 is provided on the optical
path of one of the two beams of collimated light from the
first beam splitter 103 and reflects the incident beam of
collimated light to be launched into the second beam
splitter 106.

The second reflector 105 is provided on the optical
path of the other of the two beams of collimated light
from the first beam splitter 103 and reflects the
incident beam of collimated light to be launched into the
second beam splitter 106.

The two beams of collimated light reflected by the
first reflector 104 and the second reflector 105 to be
launched into the second beam splitter 106 are recombined
and emerge from said second beam splitter 106 at two end
faces that differ from the two incident end faces.

The reflected beam from the first reflector 104 and
the reflected beam from the second reflector 105 that are
to be recombined at the second beam splitter 106 have
their optical axes adjusted to incline slightly. These
two optical axes can be inclined by means of either the
reflectors or the beam splitter and either method will
do.

The third beam splitter 112 is provided on the optical axis of the light emerging from one of the two exit end faces of the second beam splitter 106. The light intensities emerging from the two exit end faces of the second beam splitter 106 have inverting characteristics but the third beams splitter 112 may be provided adjacent whichever of the two exit end faces. The third beam splitter 112 splits the incident interference light into two beams, one being directed to the first photo-detector 109 and the other directed to the second photo-detector 110.

One of the two split beams of interference light emerging from the third beam splitter 112 is launched into the first photo-detector 109 after passing through the first slit 107 provided on its optical axis. Similarly, the other of the two split beams of interference light is launched into the second photo-detector 110 after passing through the second slit 108 provided on its optical axis. The subsequent operations are the same as in the first embodiment.

While the second embodiment described above has the same advantage as the first embodiment, it offers another advantage in that the reflected light from neither the first reflector 104 nor the second reflector 105 returns

- 27 -

to the input fiber 101, thereby insulating it from any adverse effects.

In addition, using an interferometer of the described design, one can fabricate a wavelength monitor having a small difference in pathlength and offering broad FSR wavelength characteristics.

Third embodiment

Fig. 3 is a diagram showing the configuration of a wavelength monitor 30 according to the third embodiment of the invention. In Fig. 3, the components which are the same as those shown in Figs. 1 and 2 are identified by the same numerals.

As Fig. 3 shows, the wavelength monitor 30 of the third embodiment has a Mach-Zehnder interferometer optical system 31 comprising a collimating lens (optical element) 102 for collimating the incident light from an input fiber (light input section) 101, a first beam splitter 103 for splitting the incident collimated light into two beams, a first reflector 104 and a second reflector 105 for reflecting the respective split beams of collimated light from the first beam splitter 103, and a second beam splitter 106 for recombining the two beams of reflected light.

The optical system 31 has an interference pattern generating means 32 which inclines the wavefronts of the reflected beams from the first reflector 104 and the second reflector 105 after they are recombined at the second beam splitter 106, thereby generating an interference pattern in the light intensity distribution in an interference light beam plane, and this interference pattern generating means 32 is realized either by inclining the first reflector 104 and/or the second reflector 105 or by inclining the first beam splitter 103 and/or the second beam splitter 106.

The optical system 31 further includes a first slit 107 and a second slit 108, as well as a first photo-detector 109 and a second photo-detector 110 that are securely provided on an optical base platform (not shown); another component of the optical system 31 is a signal processing circuit (signal processing means) 111 for processing the signals from the first photo-detector 109 and the second photo-detector 110.

Next, we describe the capabilities and operations of the third embodiment on the following pages.

The operations up to the stage of recombining the reflected beams at the second beam splitter 106 are the same as in the second embodiment.

The second beam splitter 106 recombines the two beams of reflected parallel light from the first reflector 104 and the second reflector 105 and allows them to emerge from two end faces that differ from the two incident end faces.

One of the two split beams of interference light emerging from the second beam splitter 106 is launched into the first photo-detector 109 after passing through the first slit 107 provided on its optical axis. Similarly, the other of the two split beams of interference light is launched into the second photo-detector 110 after passing through the second slit 108 provided on its optical axis. However, the light intensities emerging from the two exit end faces of the second beam splitter 106 have inverting characteristics.

The subsequent operations are the same as in the second embodiment.

It should, however, be noted that the positions of the first and second slits provided on the optical axes of the beams emerging from the second beam splitter 106 are different from their positions on the optical axes of the beams emerging from the third beam splitter 112 in the aforementioned second embodiment.

According to the third embodiment of the invention, the third beam splitter 112 in the second embodiment can

be eliminated and this contributes to reducing cost and size.

Fourth embodiment

Fig. 4 is a diagram showing the configuration of a wavelength monitor 40 according to the fourth embodiment of the invention. In Fig. 4, the components which are the same as those shown in Figs. 1 - 3 are identified by the same numerals.

As Fig. 4 shows, the wavelength monitor 40 of the fourth embodiment has a Mach-Zehnder interferometer optical system 41 comprising a collimating lens (optical element) 102 for collimating the incident light from an input fiber (light input section) 101, a first beam splitter 103 for splitting the incident collimated light into two beams, a first reflector 104 for reflecting one of the two beams of collimated light as split by the first beam splitter 103, a second reflector 105 for reflecting the collimated light reflected from the first reflector 104, and a second beam splitter 106 for recombining the other of the two beams of collimated light as split by the first beam splitter 103 with the reflected light from the second reflector 105.

The optical system 41 has an interference pattern generating means 42 which inclines the wavefront of the

reflected light from the second reflector after
recombination of beams by the second beam splitter 106
and the wavefront of the other of the two beams of
collimated light as split by the
first beam splitter 103, thereby generating an
interference pattern in the light intensity distribution
in an interference light beam plane, and this
interference pattern generating means 42 is realized
either by inclining the first reflector 104 and/or the
second reflector 105 or by inclining the first beam
splitter 103 and/or the second beam splitter 106.

The optical system 41 further includes a third beam
splitter 112, a first slit 107 and a second slit 108, as
well as a first photo-detector 109 and a second photo-
detector 110 that are securely provided on an optical
base platform (not shown); another component of the
optical system 41 is a signal processing circuit (signal
processing means) 111 for processing the signals from the
first photo-detector 109 and the second photo-detector
110.

Next, we describe the capabilities and operations of
the fourth embodiment on the following pages.

The first reflector 104 is provided on the optical
path of one of the two split beams of collimated light
from the first beam splitter 103 and reflects the

incident beam of collimated light toward the second reflector 105.

The second reflector 105 is provided on the optical path of the collimated light reflected from the first reflector 104 and reflects the incident collimated light to be launched into the second beam splitter 106.

The other of the two beams of collimated light as split by the first beam splitter 103 and the collimated light reflected from the second reflector 105 are launched into the second beam splitter 106, where they are recombined and emerge from two end faces that differ from the two incident end faces.

The third beam splitter 112 is provided on the optical axis of the light emerging from the second beam splitter 106 at one of the two exit end faces. The light intensities emerging from the two exit end faces of the second beam splitter 106 have inverting characteristics but the third beam splitter 112 may be provided adjacent whichever of the two exit end faces.

The subsequent operations are the same as in the third embodiment.

The fourth embodiment parallels the second embodiment in that the reflected light from neither the first reflector 104 nor the second reflector 105 returns

to the input fiber 101, thereby insulating it from any adverse effects. On the other hand, using an interferometer of the described design, one can fabricate a wavelength monitor having a great difference in pathlength and offering narrow FSR wavelength characteristics.

Fifth embodiment

Fig. 5 is a diagram showing the configuration of a wavelength monitor 50 according to the fifth embodiment of the invention. In Fig. 5, the components which are the same as those shown in Figs. 1 ~ 4 are identified by the same numerals.

As Fig. 5 shows, the wavelength monitor 50 of the fifth embodiment has a Mach-Zehnder interferometer optical system 51 comprising a collimating lens (optical element) 102 for collimating the incident light from an input fiber (light input section) 101, a first beam splitter 103 for splitting the incident collimated light from the optical element 102 into two beams, a first reflector 104 for reflecting one of the two beams of collimated light as split by the first beam splitter 103, a second reflector 105 for reflecting the collimated light reflected from the first reflector 104, and a second beam splitter 106 for recombining the other of the

- 34 -

two beams of collimated light as split by the first beam splitter 103 with the reflected light from the second reflector 105.

The optical system 51 has an interference pattern generating means 52 which inclines the wavefront of the reflected light from the second reflector 105 after recombination of beams by the second beam splitter 106 and the wavefront of the other of the two beams of collimated light as split by the first beam splitter 103, thereby generating an interference pattern in the light intensity distribution in an interference light beam plane, and this interference pattern generating means 52 is realized either by inclining the first reflector 104 and/or the second reflector 105 or by inclining the first beam splitter 103 and/or the second beam splitter 106.

The optical system 51 further includes a first slit 107 and a second slit 108, as well as a first photo-detector 109 and a second photo-detector 110 that are securely provided on an optical base platform (not shown); another component of the optical system 51 is a signal processing circuit (signal processing means) 111 for processing the signals from the first photo-detector 109 and the second photo-detector 110.

Next, we describe the capabilities and operations of the fifth embodiment on the following pages.

The operations up to the stage of recombining the reflected beams at the second beam splitter 106 are the same as in the fourth embodiment.

The second beam splitter 106 recombines the other of the two beams of collimated light as split by the first beam splitter 103 with the collimated light reflected from the second reflector 105. The recombined beams emerge from the second beam splitter 106 at two end faces that differ from the two incident end faces.

The subsequent operations are the same as in the aforementioned third embodiment.

According to the fifth embodiment of the invention, the third beam splitter 112 in the fourth embodiment can be eliminated and this contributes to reducing cost and size.

In the first to fifth embodiments described above in detail, the second beam splitter 106 in the first embodiment and the third beam splitter 112 in the second and fourth embodiments may employ the reflecting prism 206 (see Fig. 6) which is shown in JP 11-034697 A, "Wavelength Change Measuring Apparatus", and hereby incorporated as a conventional reference. Light may be reflected by the reflecting prism 206 to both sides as taught in JP 11-034697 A, supra but obviously, only one half of the beam diameter may be reflected.

The interference pattern generating means may be
realized by inserting a wedge substrate (such as a glass
plate in wedge shape having one side formed at an angle
with the other side) into one of the optical paths in the
optical system.

As detailed above, in the wavelength monitor
according to the present invention, the width and
position of the slit provided in front of each photo-
detector are adjusted after fixing the individual
components and this has the advantage of producing
interference light intensity signals having an ideal
phase difference.

In addition, the specially designed step mirror
which has been used in the conventional wavelength
monitors is no longer necessary, contributing to cost
reduction. Since the diffraction occurring at the
boundary between the step and the non-step area of the
step mirror is absent, there is no such problem as the
occurrence of distorted interference optical signals.

In the wavelength monitors, the reflected light from
neither of the two reflectors returns to the input fiber,
thereby insulating the input section from any adverse
effects.

- 37 -

- 38 -

The wavelength monitors use a smaller number of
components and, hence, can be constructed at lower cost
in smaller size.